Appendix 2.8 B

Task 2.8 B: Scale-Up of a Microfiltration System in Municipal Wastewater Reclamation

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Legal Notice

Acknowledgement

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable and reliable energy services and products to the marketplace.

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Pier funding efforts are focused on the following six RD&D program areas:

- Building End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research

What follows is the final report for *Electrotechnologies for the production of potable water and the protection of the environment* (Task 2.8 Scale Up), conducted by the Orange County Water District. This report is entitled Scale up of a microfiltration system in municipal wastewater reclamation. This project contributes to the Energy-Related Environmental Research program.

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Executive Summary

Introduction

The Orange County Water District (OCWD) is planning to implement a major expansion to the current Water Factory 21 (WF 21)wastewater reclamation facility. The current facility has a capacity of 15 million gallons per day (mgd). The plant expansion project, known as the Groundwater Replenishment System (GWR System), will increase capacity to 70 mgd using microfiltration (MF), reverse osmosis (RO), and ultraviolet disinfection (UV) processes. OCWD has been testing MF system for over ten years on a pilot-scale basis using system with flowrates of 10-30 gallons per minutes (gpm). In order to establish the operational characteristics and economics of using MF technology testing on larger scale was needed. A demonstration-scale MF system (600 gpm capacity) was procured from the Pall Corporation and it was tested in parallel with an existing pilot-scale Pall MF system.

Project Approach

A four-module pilot MF system and a demonstration-scale MF system from the Pall Corporation were run in parallel from June 1999 to September 2000. Each system was fed secondary effluent from the Orange County Sanitation District Plant 1 facility. This is the same feedwater to the current WF 21 facility. The secondary effluent feed was dosed with 3-5 parts per million (ppm) of chloramines residual. Various operational settings were run on each system to determine the optimal operational characteristics. Specifically the air scour and reverse flush intervals were varied. Also the duration of each of these processes was varied. These two processes are used by both systems to deter fouling on the membrane fibers. In addition to optimizing the operational settings on the demonstration system, the cleaning procedure was also optimized. Various chemical combinations were tried along with various cleaning lengths.

Project Outcomes

First it was found that it is possible to increase the output of an MF system by increasing the surface area of membrane available and that this can be done without increasing the cleaning requirements. Secondly, it was found that adequate contact time with prechlorination is essential for the control of microbial fouling on the membrane surface. Third, it was found that the full-scale MF system worked best when operated at a 90% recovery rate, a backwash interval of 15 minutes, and a flux of 24 gallons per square foot per day (gfd). Fourth it was found that the optimum cleaning procedure involved a caustic cleaning with a 2% sodium hydroxide solution and a 5000 ppm chlorine concentration followed by a acid cleaning using a 2% citric acid solution. Fifth, it was found that the amount of energy required by the full-scale MF system was 400 kWh per mgd. Finally, it was found that it is possible to expose the membrane modules on the Pall MF system to direct sunlight without degradation of the membrane module housing.

Conclusions and Recommendations

The performance of a demonstration scale microfiltration system on clarified secondary effluent was evaluated at the Orange County Water District. The demonstration system consisted of 50 six-inch modules; previous systems evaluated at OCWD consisted of 4 five-inch modules. Operation of the demonstration system established that it was possible to increase the output of a MF module by increasing the surface area without increasing the module cleaning requirement. The overall process recovery of the demonstration microfiltration system was found to be 90% at a flux of 24 gallons per square foot per day and a backwash interval of 15 minutes. The optimum cleaning procedure involved a caustic cleaning with a 2% sodium hydroxide solution and 5000 ppm chlorine followed by a acid cleaning using a 2% citric acid solution. The amount of energy required by the full-scale microfiltration system is 400 kWh per million gallons of water treated.

The MF technology was shown to be economical for the reclamation of wastewater sources and that the process can be used for municipal size applications. This technology could be the main source of treatment for many of the future reclamation projects slated for construction in the state of California.

Abstract

The performance of a full-scale demonstration microfiltration system was compared with a pilot scale system. The full-scale system used a six inch diameter membrane module while the pilot system had a five inch diameter module. It was shown that the scale up of the Pall microfiltration membrane system did not decrease the interval between cleaning observed for their pilot scale system. The overall process recovery of the demonstration microfiltration system was found to be 90% at a flux of 24 gallons per square foot per day and a backwash interval of 15 minutes. The optimum cleaning procedure involved a caustic cleaning with a 2% sodium hydroxide solution and 5000 ppm chlorine followed by a acid cleaning using a 2% citric acid solution. The amount of energy required by the full-scale microfiltration system is 400 kWh per million gallons of water treated.

Task 2.8 –Scale-Up of Microfiltration System

1.0 Introduction

1.1 Background and Overview

Microfiltration (MF) is a member of the family of pressure driven, liquid phase membrane separation processes, that includes ultrafiltration, nanofiltration and reverse osmosis. Microfiltration membranes are used in both industrial and municipal water treatment to remove particles and colloids larger than 0.1 microns from solution and are alternatives to the conventional solids separation processes such as granular media filtration and clarification by flocculation and settling.

Microfiltration was chosen as the subject for scale up investigations because of the processes critical role in a wastewater reclamation project proposed by the Orange County Water District called the Groundwater Replenishment System (GWR System). The GWR System will treat secondary wastewater effluent using a three step treatment processes consisting of microfiltration (MF), reverse osmosis (RO), and ultraviolet disinfection (UV). Planning for the GWR System has involved rigorous testing of both commercially available and emerging MF, RO and UV systems. For convenience, the majority of this testing has occurred using pilot scale equipment. The pilot scale approach has worked well for the RO because it is a mature process, with many full scale RO facilities in operation that provide critical design information for the GWR System. However, MF is a developing process, with a limited number of larger applications. Consequently, some of the performance criteria that was established at the pilot scale needs to be validated at the production scale. Therefore the goal of this task was to determine key design criteria for microfiltration for the treatment of secondary effluent.

1.2 Project Objectives

The objective of the “scale up” study was to evaluate the performance of a microfiltration system on a scale that yields useful design information for municipal wastewater reclamation projects like the GWR System. To this end several investigations were initiated to answer the following critical design questions for large scale reclamation applications:

1. Is it possible to increase the output of a MF module by increasing the surface area without increasing the module cleaning requirements?
2. How important is prechlorination in the control of microbial fouling on the membrane surface?
3. What is the effective process recovery of MF system consisting of multiple modules (What volume of waste is produced per volume of water treated)?
4. How often is it necessary to clean a MF system that consists of multiple modules and what is the most effective cleaning solution?
5. What are the energy requirements for a system consisting of multiple membrane modules?
6. Is it necessary to install the system in a building or can the materials used to construct a multiple MF system stand up to repeated exposure to sunlight, wind and rain?

1.3 Report Organization

The following report presents information collected from both pilot and demonstration investigations. The project approach contains information on the equipment specifications and operational protocols while detailed results for the six key design questions are presented in section 3.0 project outcomes. Finally, the conclusions and recommendations section contains a summary of the major results, an evaluation of the potential for commercialization, an estimate of the need for further work and an assessment of the benefits of the research for California.

2.0 Project Approach

Two microfiltration modules, the PALL USV5023 (5 inch diameter) and the USV6203 (6 inch diameter) were used in the scale up studies (Table 1). Both modules used identical hollow fiber polyvinylidene fluoride membranes with a nominal pore size of 0.1 microns. The modules were installed in pilot and demonstration scale microfiltration (MF) systems at the Orange County Water Districts, Water Factory 21 facility in Fountain Valley, California. The MF systems operated on clarified effluent from an air activated sludge process operated by the Orange County Sanitation District. The clarified secondary effluent contained, 1100 ppm total dissolved solids, 10-11 mgL^{-1} total organic carbon, 5-15mgL^{-1} biological oxygen demand, 5 mgL^{-1} suspended solids, 15 - 20 mgL^{-1} ammonia and approximately 10^6 coliforms per 100 ml. The turbidity was typically 2 NTU, however, it is not uncommon to have turbidity excursions of >15 NTU.

The experimental design was based on monitoring performance of a pilot scale system, containing four of the smaller USV 5023 (5-inch) modules, rated at 36 gallons per minute (gpm) compared with that of a 600 gpm demonstration scale system, containing fifty of the USV6203 (6-inch) diameter modules, rated at 600 gpm.

The pilot system was delivered to the site as a skid mounted self contained unit containing Four PALL Microza USV 5023 modules (Plate 1). Clarified secondary effluent, containing a 3 - 5 ppm combined chlorine residual, was screened through a 120 micron filter and stored in a feed tank mounted on the unit. The feed tank served as the location of prechlorination and was also used to prepare and dose the cleaning chemicals. A dedicated feed pump provides driving force for the process. The pump discharges into a single feed header that connects to the bottom of each module. The pressurized effluent enters the module and contacts the outer surface of the individual hollow fiber membranes. Microfiltered filtrate passes across the membrane and collects on the inside (or lumen) of the fiber while suspended solids, bacteria and fine colloids are retained on the outer (or shell) membrane surface. Filtrate was collected in a dedicated 50 gallon tank which served as a reservoir for backwash water. The top of the modules are connected via a pneumatically actuated valve to a reject manifold. If the valve is closed the membrane process operates in the “dead-end” or direct flow mode. Under this mode of operation the retained materials are discharged from the module only when this valve opens. Alternatively, if this valve is open during the filtration cycle the membranes operate in a cross flow mode. Under this mode of operation the solids are continuously carried out of the module, return to the feed tank and recirculated through the module. The reciriculation rate or cross flow velocity can be controlled via a flow control loop consisting of a flow meter on the reject manifold connected to the pneumatic valve. Retained solids are dislodged from the membrane surface at preset time intervals by either scouring the membrane with air bubbles, reversing the flow of filtrate across the membrane or a combination of the two. Compressed air for the air scour was supplied through a passive connection to the main plant air at WF21. The System operates as a continuous process at a constant flux (flow per unit area per unit time) between backwashes, however, the filtration process is best described as a multiple batch process as filtrate is not produced during either the backwash or the air scrub.

The demonstration scale system was procured and delivered to site as a series of components:

- A feed module containing the feed pump and influent strainers.
- A valve and module assembly containing the filtration, backwash and cleaning valves, module racks, feed, filtrate and backwash manifolds
- A backwash and cleaning module containing two cleaning tanks (acid & alkali), cleaning pumps, backwash water holding tank and backwash pump.
- An air system assembly containing the air compressors, filters, drier’s and air receiver.

The system components were installed an assembled over a three month period between January and March, 1999. The MF system consisted of fifty USV 6023 modules arranged in two rows of twenty five (Plate 2). In order to evaluate the ability of the demonstration system to withstand constant exposure to wind, rain and direct sunlight, only eight of the fifty membranes were coated with a UV resistant polyurethane coating. At the end of the test period the outer surface of the modules will be examined to assess the potential damage caused by exposure to direct UV light.

The mode of operation for the demonstration system was identical to the pilot in respects with the exception of the chlorine addition system; chlorine was injected immediately before the feed pump and had negligible (< 10 seconds) contact time before contacting the membrane (The contact time on the pilot was approximately five minutes based on the average detention time in the feed tank. Start up issue were addressed for three months following the installation of the system (April 1999 to June 1999). These issues included: programming of computer control system, fine tuning of valve operation, and optimization of air flow from the compressed air system.

The pilot and demonstration systems were to be operated in tandem. The bulk of the data was collected from the demonstration scale system to establish performance criteria; the pilot system was to be operated to compare the fouling rates of the 5-inch and 6-inch modules and determine the impact of chlorination on performance.

The operation of the demonstration system was structured to establish the impact of the reverse flow frequency, air scour frequency and backwash sequence on the membrane fouling. Theses factors combine to determine the efficiency of the backwash to control fouling. The overarching objective of these experiments was to identify the optimum backwash combination for a scaled up system. Membrane fouling was measured as the rise in transmembrane pressure. Under direct flow operation, the transmembrane pressure is defined as the difference between the pressure on the shell side of the module (feed pressure) and the lumen side of the module (filtrate). Under cross flow operation the transmembrane pressure is defined as the difference between the average of the module inlet and outlet feed pressure and the filtrate pressure. The membranes were chemically cleaned before each test run and were operated at a constant flux. The test run was terminated when the transmembrane pressure reached 25 pounds per square inch.

The performance of the demonstration system was evaluated under three backwash scenarios (Table 2).

- Scenario A - Aggressive backwash conditions consisting of reverse flow every fifteen minutes and an air scour every 30 minutes.
- Scenario B - Moderate backwash conditions consisting of reverse flow every twenty minutes and air scour every 40 minutes.
- Scenario C - Benign backwash conditions consisting of reverse flow every thirty minutes and air scour every sixty minutes

Three alternative backwash combinations were investigated under each scenario; these combinations were based on the following sequencing of the air flow and the reverse filtrate flow (Table 2).

The chemical cleaning procedure for the demonstration system consists of recirculation of a citric acid solution through the membranes for a period of time followed by a soak of the membranes in the citric acid solution. After the citric acid portion of the cleaning is complete the same procedure is done using a caustic solution (sodium hydroxide). The Pall Corporation suggested the use of a 2% citric acid solution and a 0.5% caustic solution mixed with 600 ppm chlorine. It was also recommended by Pall that each solution be recirculated through the membranes for 30 minutes followed by a one hour soak. This cleaning procedure was used during the first six months of operation (June 1999 to December 1999). During the next three months (January 2000 to March 2000) a different cleaning procedure was used. The caustic cleaning step was done before the citric acid cleaning step. The concentration of caustic solution was increased to 2% with an increased chlorine concentration of 5000 ppm. The caustic solution was recirculated through the membranes for 2 to 3 hours and allowed to soak on the membranes overnight. After the overnight soak in caustic solution the citric acid cleaning step occurred. The citric acid solution was recirculated through the membranes for 2 to 3 hours and then allowed to soak on the membranes for 1 to 2 hours. Beginning in March 2000 a third cleaning procedure was implemented. The new cleaning procedure remained in effect until the end of the test period. This procedure consisted of a 2% caustic solution with 5000 ppm chlorine being recirculated through the membranes for 10 to 12 hours and then the solution was rinsed without a soak step. The membranes were then subjected to a citric acid cleaning. A 2% citric acid solution was recirculated through the membranes for 2 to 3 hours and then rinsed without a soak step.

3.0 Project Outcomes

1. *It is possible to increase the output of a MF module by increasing the surface area without increasing the module cleaning requirement.*
2. *Adequate contact time during pre-chlorination is essential for the control of microbial fouling of the membrane surface.*

The pilot and the demonstration systems operated at the same flux (loading rate) on clarified secondary effluent. Under loading rates the 6” module appeared to reach critical transmembrane pressure and foul faster than the 5” module (Figure 1). This result was not expected since the fibers used in 6” modules are exactly the same as those in 5” modules and the length of a 6” module is the same as a 5” module. (Table 1). Consequently, it is reasonable to expect that the hydraulic loss in the fiber lumens should be the same regardless the diameter of the module. In addition, the packing density of a 6” module is 225 fibers /in^2 cross-section area, compared to 244 fibers /in^2 cross-section area for a 5” module. This represents approximately an 8% decrease in packing density. Therefore, the removal of retained solids, bacteria and small colloids should theoretically be easier from the larger diameter module. Notwithstanding this the 6” module fouled at approximately 3 times the rate (1.76 psi/day) as the 5” module (0.58 psi/day).

The two significant differences between the set up of the pilot system and the set up of the demonstration system was the sequencing of the backwash and the chlorine contact time (Table 3). Given that the clarified secondary effluent contains between 106-107 coliforms per 100 ml it was reasonable to expect that biological moieties in the feed water would make a significant contribution to the fouling of the membrane surface. To test this theory the chlorine injection point on the pilot system was relocated from the inlet to the feed tank to the pump intake manifold. This reduced the chlorine contact time from about 5 minutes to a few seconds. Under these conditions the performance of the pilot unit with 5” modules was comparable, if not worse, than the demonstration system with the 6” modules (Figure 2). As noted in the figure, the pilot unit was shutdown for three days and during this time the modules were stored with chlorinated filtrate to prevent microbial growth. It is expected that the TMP rise for the 5” modules would have been greater if the pilot unit had been running continuously. Moreover, it is most likely that the difference in chlorine contact time, rather than module diameter, was the cause for performance differences in the pilot and demonstration system.

Therefore the tentative conclusion based on this data is that it is possible increase the surface area of the microfiltration module without incurring excessive fouling of the membrane. In addition, fouling of the microfiltration membrane is strongly contingent upon adequate chlorine contact time.

3. *The overall process recovery of the full-scale Pall microfiltration system was found to be 90% at a flux of 24 gallons per square foot per day and a backwash interval of 15 minutes.*

In order for microfiltration to be an effective pretreatment process for the reverse osmosis system it is necessary for the membranes to operate continuously for a minimum of 21 days without chemical cleaning. After the first 30 days of operation of the demonstration unit it was apparent that both the benign (air scour every 60 minutes) or moderate (air scour every 40 minutes) backwash protocols were ineffective at controlling fouling. Under these conditions, a chemical cleaning was required every 3 to 6 days to restore membrane permeability. Consequently, the system was operated using an aggressive backwash protocol for the remainder of the evaluation in an effort to increase the interval between chemical cleanings. Under these conditions the system operated at a loading rate of 12 gallons per minute per module, equivalent to a flux of 33 gallons per square foot per day, with a reverse flush step occurring every 15 minutes and the air scour step occurring every 30 minutes. However, operation using an aggressive backwash protocol only increased the cleaning interval to approximately 13 days. A cleaning interval of 21 days was only achieved after the loading rate on the membranes was reduced by 25% from 12 gpm/module to 9 gpm/module which was equivalent to a flux of 24 gfd. Under these conditions the system operated at a recovery of 90% and it was possible to achieve a 21 day between cleanings (Figure 3) provided that a specific cleaning protocol was employed (see below). The backwash sequence was consolidated to have the air scour and reverse flush steps occur simultaneously every 22 minutes for 110 seconds. This step was then followed by 30 seconds of reverse flush alone. This set up also resulted in system recovery of 90%.

4. *The optimum cleaning procedure involved a caustic cleaning with a 2% sodium hydroxide solution and 5000 ppm chlorine followed by a acid cleaning using a 2% citric acid solution.*

The standard cleaning procedure for membrane systems is based on the use of a high pH step to hydrolyze organic molecules and low pH to remove inorganic species. A strong oxidant can also be introduced to the high pH clean to oxidize the retained organic compounds. The cleaning system on the demonstration plant had facilities for both a caustic and acid clean. Several variations on the low pH/high pH cleaning protocol were evaluated to identify the optimum cleaning procedure. The efficacy of the cleaning procedure was based on the reduction in transmembrane pressure after the chemical clean.

The first cleaning protocol was based on a low pH step followed by a high pH step. The membranes were exposed to a 2% citric acid solution with 30 minutes of recirculation followed by a 60 minutes with no recirculation. The membranes were then exposed to a 0.5% caustic (sodium hydroxide) and 600 ppm chlorine solution for 30 minutes without recirculation. This resulted in the use of 200 pounds of powdered citric acid, 12 gallons of 40% liquid sodium hydroxide, and 5 gallons of 12.5% liquid sodium hypochlorite (chlorine) per chemical cleaning. The results obtained using this cleaning protocol were erratic; on some occasions it was possible to operate for 21 days, however, on other occasions the cleaning interval was less than 21 days.

The second cleaning procedure reversed the order of the low pH and high pH cleanings. The strength of the caustic solution was also increased from 0.5% to 2% and the concentration of chlorine added to the caustic solution was increased from 600 ppm to 5000 ppm. The recirculation time of the caustic solution was increased from 30 minutes to 10 hours. In addition, the soak step was eliminated. The citric acid cleaning solution strength was not changed but the recirculation time was increased from 30 minutes to 2 hours. As was done with the caustic solution the citric acid solution the soak step was eliminated. The increase in recirculation time proved to be more effective in removing the fouling on the MF membranes than soaking. Also, the nature of the fouling on the MF membranes was found to be mainly organic in nature. Organic fouling is caused by the accumulation of particulate and dissolved organic matter, such as total organic carbon (TOC), on the walls of the MF fibers. This accumulation results in a biological slime layer adheres tightly to the fibers so that it cannot be completely removed by the reverse flush and air scour processes. Organic fouling is removed by the caustic solution so the concentration of the caustic solution was increased along with the recirculation time of the solution. The new cleaning procedure allowed for a three week average cleaning interval for the Pall full-scale MF system.

5. *The amount of energy required by the full-scale Pall microfiltration system is 400 kWh per million gallons of water treated.*

The amount of energy consumed by the Pall system was calculated by tracking the electricity usage of the various components of the system. These include the feed pump, reverse flush pump, compressed air system, heaters for the cleaning system and the computer control system.

The factors that effect the energy usage of the MF system include: process recovery, cleaning intervals, and flux rate among many others. The process recovery for the Pall MF system was optimized to 90%. Process recovery effects energy usage because the amount of water produced is based on system recovery. The more water that can be produced from the system at one time reduces the amount of energy needed. The cleaning interval also has a significant effect on energy usage. If the cleaning interval is short the amount of cleanings are increased. Chemical cleanings require the use of heaters to heat chemical solutions and the use of pumps to circulate the chemical through the membranes. The flux rate has the greatest effect on the energy required for microfiltration systems. The flux is measure of the volume of water that is able to be treated per area of membrane. In order to optimize energy usage while maintaining a reasonable cleaning interval is vital to insure that the MF process is as efficient as possible. For the Pall MF system a flux of 24.1 gfd was found to be ideal. The main components that require energy for the Pall MF system include: feed pumps, reverse flush pumps, cleaning solution pumps, compressor systems, cleaning tank heaters, and miscellaneous equipment. The miscellaneous equipment includes lights, computer controls, and gauges. The largest energy usage is for the feed pumps. These pumps bring the water to be treated into the membrane under enough driving pressure to force the water through the membranes. It is estimated that the feed pumps for an 80 mgd system would require nearly 5.5 million kWh of energy per year. A breakdown of the estimated energy usage for the main components of the Pall system based on a 80 mgd capacity plant is shown in the (Table 3). These estimations were based on the testing done using the Pall full-scale MF system at OCWD.

6. It is possible to operate a full scale system with some exposure to direct sunlight.

Eight modules were installed on the full scale system that were coated with a special ultraviolet-resistant finish (Plate 3). This finish was formulated by Asahi Corporation to protect against ultraviolet deterioration of the plastic housing on the membrane module. The coating applied the eight modules installed was a polyurethane based paint. This type of paint is commonly used for the coating of automobile plastic bumper for the improvement of weather resistance. The appearance of these modules was darker in color as compared to the untreated modules. This made recognition of these modules easy. The appearance of the specially coated modules was observed every month for obvious signs of deterioration. Over the course of a year and a half no deterioration was found on either the coated or the uncoated modules.

4.0 Conclusions and Recommendations

4.1 Conclusions

The three week cleaning interval was necessary as part of the design for the proposed GWR System. In order to meet the requirement established by OCWD for a three week interval between chemical cleanings an ideal process recovery for the full-scale MF system of 90% was established. The 90% recovery figure is ideal for a system flux of 24.1 gfd for operation on secondary effluent. This recovery was established through over one year of testing at the OCWD WF21 facility using secondary wastewater effluent as the feed water source. The Pall MF system could be operated at a higher system recovery had the requirement for a three week cleaning interval not be necessary. This project if completed would result in the world's largest microfiltration plant for wastewater reclamation. The establishment of the 90% recovery number could be useful for other facilities wishing to use microfiltration for treatment of secondary effluent. The use of microfiltration has become increasingly popular due to its small space requirement and superior water quality. The process recovery for the Pall MF system is largely dependant on the interval between the air scour and reverse flush processes. The Pall MF system allows for the interval between these processes to be set to any time period. The treatment of secondary effluent requires that these process occur more often than would be necessary for surface waters. It was initially thought that the air scour and reverse flush processes could occur independently of each other. The testing at OCWD showed that this is not the case for the secondary effluent received at WF21. It was established during testing that a 22- minute interval was ideal and that the two processes occur at the same time. The exact settings for the two processes were also established as part of this testing. The settings established as part of this testing could be applied to other wastewater reclamation installations.

The cleaning procedure for the Pall MF system can be varied in many ways. The amount of chemical, the recirculation time period of chemical, soak time of the chemical are among the variables. It was important to establish an effective cleaning protocol to meet the required three week cleaning interval. Once the cleaning procedure is established the space requirements for cleaning can be determined. As with the reverse flush and air scour processes the Pall Corporation had a recommendation for the cleaning procedure. Their recommended procedure was put into use during the beginning of the testing, but was found to be inadequate. The caustic portion of the cleaning was found to be more important than the acid portion resulting in a longer recirculation time for the caustic solution than for the acid solution. This was the case because the majority of the fouling was found to be organic in nature and that the inorganic (mineral scale) fouling was not as great. This is why a nearly ten hour caustic solution recirculation was required as opposed to two hours for the acid recirculation.

4.2 Commercialization Potential

The MF process is known as a low pressure process due to the small driving pressure required to produce filtrate from the membrane fiber. The pressure is much lower than that required for reverse osmosis, but the water quality produced is not as great as that from reverse osmosis. In order for MF to be competitive with current reclamation processes the energy requirement must be similar. It was established during this testing that the energy requirement is quite comparable with conventional treatment technologies. The added benefit of MF is that the water quality produced and the process space requirement is much less than that of conventional treatment processes. In California many municipalities are faced with space shortages and increasing demands for water due to population growth. MF has great potential for addressing the future water needs of California using a process that has a low space requirement with excellent water quality. The addition of this process as a viable water and wastewater treatment option will allow California water suppliers to meet future needs at a lower price using less energy than other conventional treatment processes.

4.3 Recommendations

There are certain things that should occur in the future to insure that the process recovery established here is applicable to other installations treating similar water of similar quality.   First of all continued testing at the process settings established here should occur in order to verify their long term validity. Also, the water quality produced should be closely monitored to insure that long-term operation at these parameters does not result in decline of water quality. The integrity of the microfiltration membrane itself also needs to be observed over a long-term basis. It is possible that the operation of the system using the process parameter settings established during this testing could affect the long-term integrity of the MF membrane adversely. It is recommended that continued testing using the cleaning procedure established during testing occur. Also, the procedure established here could be easily adjusted for other installations where water quality may be differ from that at WF21. The power requirements established during this testing should be compared with those established elsewhere for MF processes. The power requirements for the Pall MF system should be compared with other conventional treatment technologies such as chemical clarification or multi-media filtration. The energy requirement for the MF process may turn out to be more than that for conventional technologies, but the superior water quality produced should be taken into account.

4.4 Benefits to California

The benefits California has already received, as part of this contract is the establishment of microfiltration technology as a viable alternative for large-scale wastewater reclamation. The use of MF technology will allow for greater reclamation to occur and reduce California's dependence on imported water sources. The long-term benefit of this project is that future reclamation projects will be able to have confidence in this technology because of the success achieved through this testing. The space requirements established are very beneficial to other California municipal reclamation agencies. Once an estimation of space required for MF is established any agency can plan for the amount of land needed to use microfiltration. In most cases the land required for MF is several times smaller than that of current reclamation treatment processes. This testing has established a good estimate of the power requirements of MF technology for wastewater reclamation. The power requirement established during this testing will allow other agencies to evaluate the MF process for use in their treatment applications.

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Glossary

MF – Microfiltration

RO – Reverse osmosis

UV – Ultraviolet

GWR System – Groundwater Replenishment System

NTU – Nephelometric Turbidity Units

gpm – Gallons per minute

psi / day – pounds per square inch per day

gfd – gallons per square foot per day

ppm – parts per million

OCWD – Orange County Water District

WF 21 – Water Factory 21

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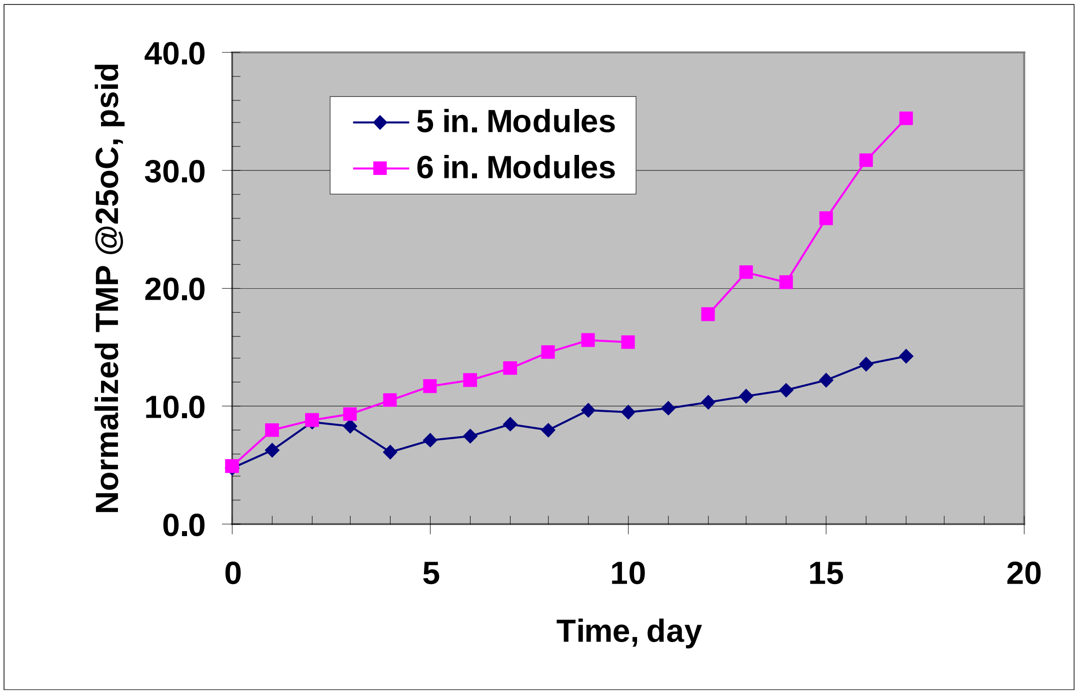

Figure 1. Performance comparison of 5" and 6" modules with different chlorine contact time

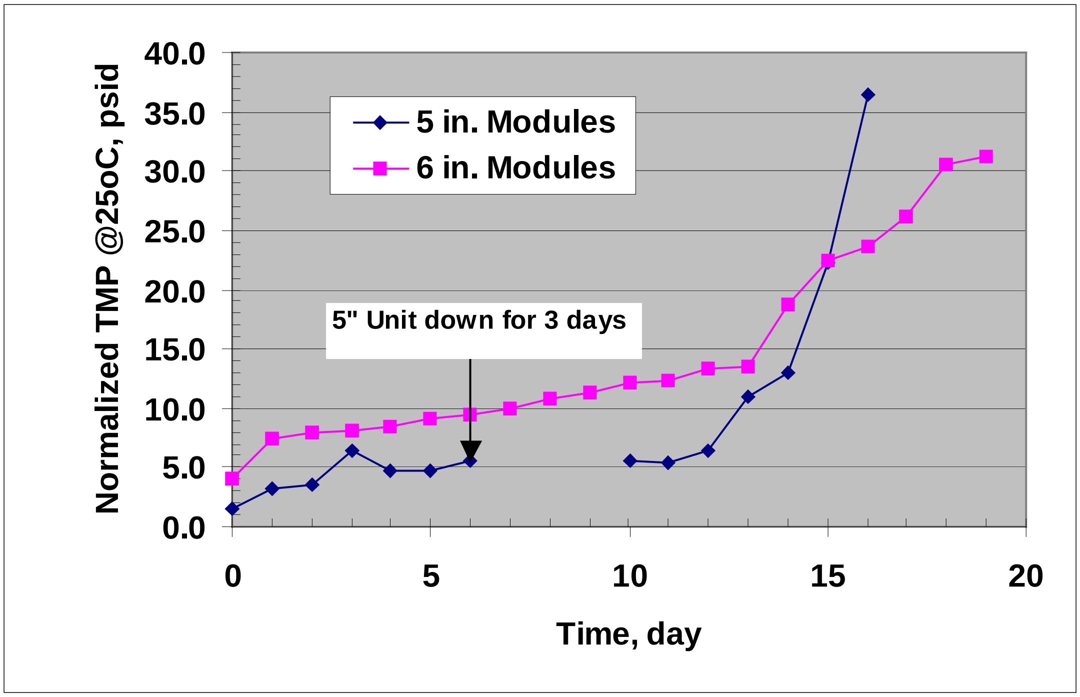

Figure 2 - Performance comparison of 5" and 6" modules with similar chlorine contact time

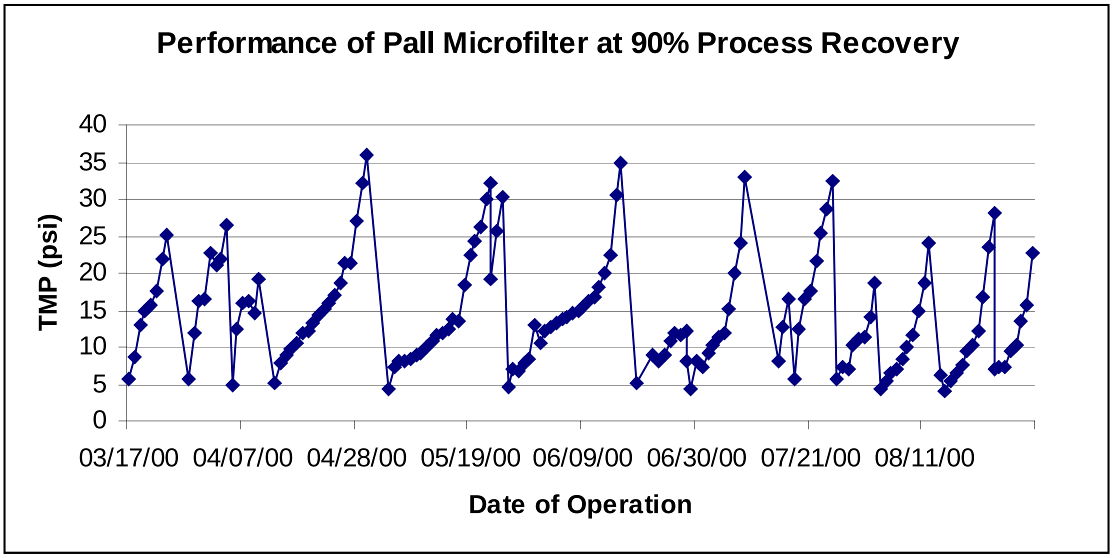

Figure 3 - Stable filtration runs with approximately 21 days between chemical cleaning based on a flux of 24.1 gfd and a backwash interval of fifteen minutes for an overall recovery of 90%.

List of Tables

Table 1 - Comparison of 6” and 5” microfiltration modules		
Manufacturer	Pall MF1	Pall MF2
Manufacturer’s Serial #	USV6203	USV-5203
Material	PVDF	PVDF
Symmetry	Symmetric	Symmetric
Pore Size (μm)	0.1	0.1
Porosity	50-60%	50-60%
Fiber O.D. (mm)	1.2	1.2
Fiber I.D. (mm)	0.68	0.68
Exposed length (m)	2	2
Fibers per module	6360	4800
Packing density (fibres/in^2)	225	244
Active Surface	shell	shell
Active Area per Fiber (m^2)	0.008	0.008
Active Area per Module (m^2)	50.1	37.7
Active Area per Module (ft^2)	539	405

Table 2 - Demonstration Scale Back-Wash Combinations			
	Aggressive Backwash	Moderate Backwash	Benign Backwash
Air Scour followed by reverse flow	Reverse flow every 15 minutes Air scour every 30 minutes	Reverse flow every 20 minutes Air scour every 40 minutes	Reverse flow every 30 minutes Air scour every 60 minutes
Reverse flow followed by air scour	Reverse flow every 15 minutes Air scour every 30 minutes	Reverse flow every 20 minutes Air scour every 40 minutes	Reverse flow every 30 minutes Air scour every 60 minutes
Air scour and reverse flow simultaneously	Reverse flow every 15 minutes Air scour every 30 minutes	Reverse flow every 20 minutes Air scour every 40 minutes	Reverse flow every 30 minutes Air scour every 60 minutes

Table 3 - Operating conditions for the USV 5023 (5” module) and the USV 6023 (6” module)

Parameter	**5” Module**	**6” Module**
Water Temperature, ^{o}C	22.8 – 27.8	22.8 – 27.8
AS Frequency/duration, min./sec.	20/110	22/110
AS Air Consumption, ft^3/ft^2 membrane	0.014	0.014
RF Frequency/duration, min./sec.	20/20	22/110*
RF Filtrate Consumption, gal./ft^2 membrane	0.024	0.024
Recovery, %	92.0	92.2

*AS and RF are carried out simultaneously for 6” modules, and sequentially for 5” modules

Table 4 - Estimate of power requirements for demonstration system	
COMPONENT	POWER REQUIRED (kWh/yr)
MF feed pumps	5,475,000
Reverse flush pumps	712, 500
MF cleaning pumps	25,000
Compressor system	787,500
Cleaning tank heaters	450,000